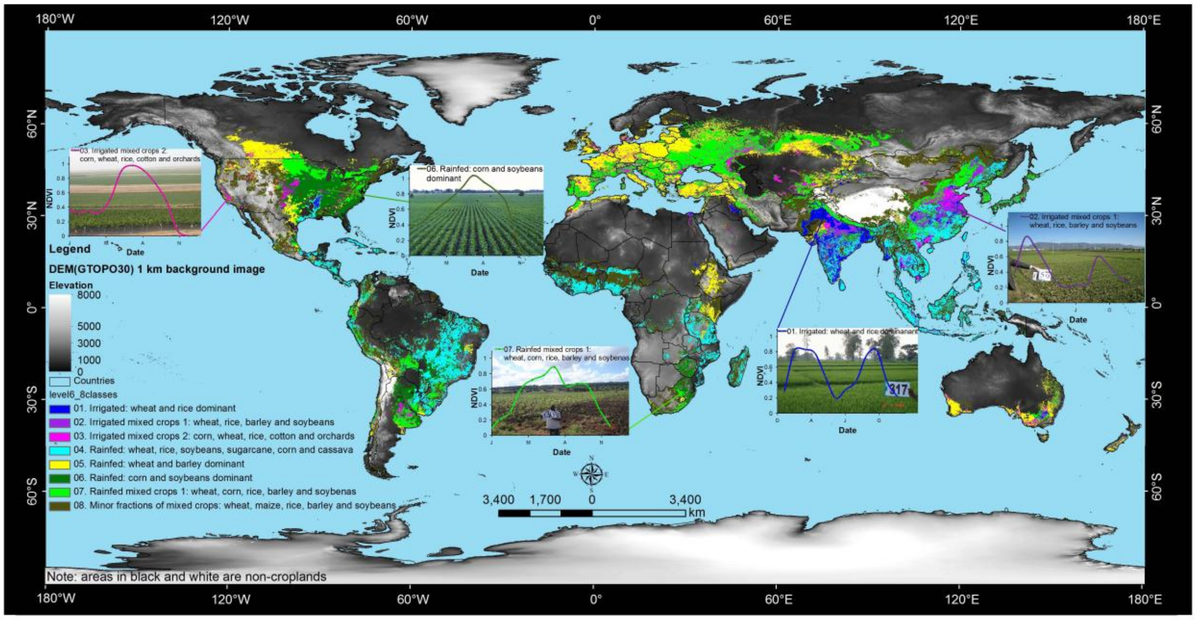
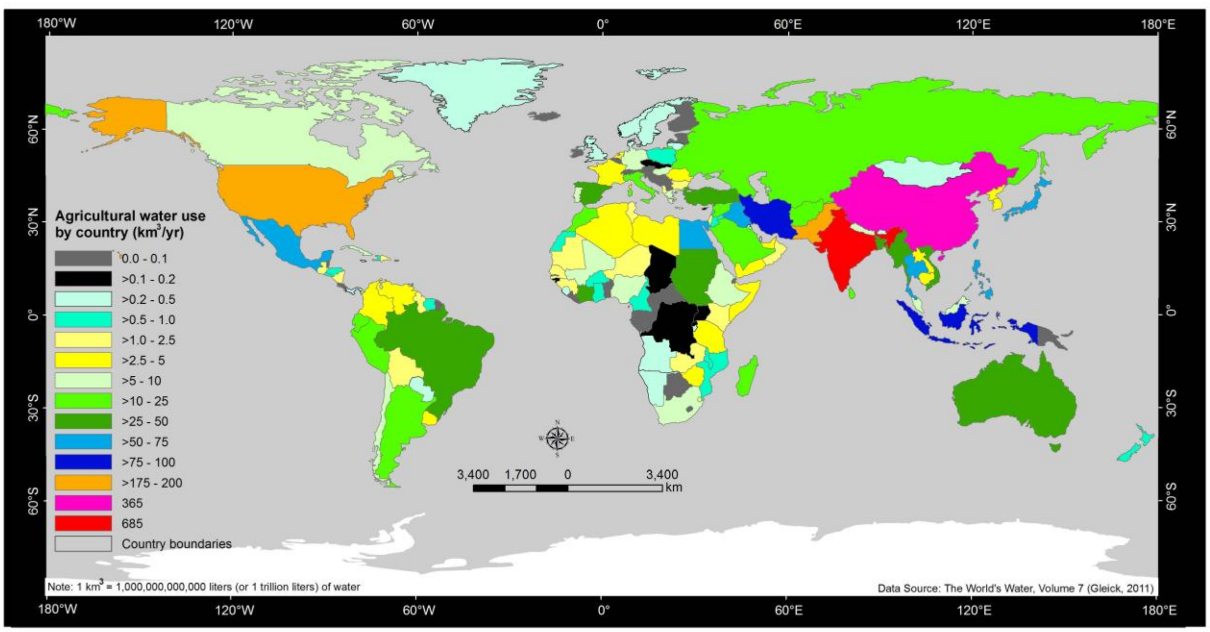
Front Page

Global Croplands and Their Water Use for Food Security in the Twenty-first Century





Dr. Prasad S. Thenkabail, PhD; Research Geographer-14; U.S. Geological Survey ; 2255 N. Gemini Dr. Flagstaff, AZ 86001; Voice mail: (928) 556-7221; Email: pthenkabail@usgs.gov; thenkabail@gmail.com

Cover page

Global Croplands and Their Water Use for Food Security in the Twenty-first Century

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Short Title: Global Croplands and Their Water Use
PI Name(s) and Complete Contact Information: **Total: 11 (3 USGS, 1 NASA, 5 University, 2 International-UK and China with alternatives from Brazil and India)**

Dr. Prasad S. Thenkabail (pthenkabail@usgs.gov; 928-556-7221)- confirmed participation
Dr. Cristina Milesi (cristina.milesi-1@nasa.gov; 650-604-6431) – confirmed participation
Dr. Chandra Giri (cgiri@usgs.gov; 605-594-2835) – confirmed participation
Dr. Mutulu Ozdogan (ozdogan@wisc.edu; 608-890-0336) – confirmed participation
Dr. Jerry Knox (j.knox@cranfield.ac.uk ; +44 (0)1234 758365) – confirmed participation
Prof. Songcai You (yousc@ieda.org.cn; 86-10-82109571 ext. 3227) – confirmed participation
Prof. Russell G. Congalton (russ.congalton@unh.edu; 603-862-4644) – confirmed participation
Prof. Alex Finkral (alex.finkral@nau.edu; 928-523-1378) – confirmed participation
Dr. Pamela Nagler (pnagler@usgs.gov; 520-626-1472) – confirmed participation
Dr. Isabella Mariotto (**is.mariotto@gmail.com**; 575-635-5838) – confirmed participation
Dr. Michell Marshall (mmarshall@umail.ucsb.edu; 805-893-8322) – confirmed participation

1.0 Project Summary:

Global climate change is putting unprecedented pressure on global croplands and their water use, vital for ensuring future food security for the world's rapidly expanding human population. The ***end of the green green revolution*** (productivity per unit of land) era has meant declining global per capita agricultural production requiring immediate policy responses to safeguard food security amidst global climate change and economic turbulence. Above all, global croplands are water guzzlers, consuming between 60-90% of all human water use. With increasing urbanization, industrialization, and other demands (e.g., bio-fuels) on water there is increasing pressure to reduce agricultural water use by producing more food from existing or even reduced: (a) areas of croplands (more crop per unit area); and (b) quantities of water (more crop per unit of water). **Given this background, a critical and urgent question facing humanity in the twenty-first century is,** *how can we continue to feed the World's ballooning populations in the twenty-first century in a scenario where croplands are decreasing (e.g., taken away for bio-fuels, urbanization), and water use is increasing (e.g., as a result of increasing temperature in a changing climate)?.* Our team will look into new and emerging strategies for increasing agricultural productivity which will consider and analyze: i) growing more of crops that consume less water (e.g., more wheat, less rice); ii) increasing water use efficiency leading to a *blue revolution* ("more crop per drop"; see Liu et al., 2008); iii) educating people to eat less water-consuming food (e.g., more vegetables and grains, less meat; more local and seasonal foods); and iv) emphasizing rainfed crop productivity to reduce stress on water-intensive irrigated croplands (FAO, 2009, Thenkabail, 2010, Thenkabail et al., 2010).

To address the above questions adequately and find solid scientific solutions, we need to fill an existing knowledge gap: the precise estimation of global croplands, their water use, and their locations. At present, the best available data only provide coarse resolution global cropland maps

(e.g., Thenkabail et al., 2009a, Thenkabail et al., 2009b, Ramankutty et al., 2008, Goldewijk, 2009, Portman et al., 2009, Ozdogan and Gutman, 2008, Siebert et al., 2006) which have huge uncertainties in: (a) estimating cropland areas, crop types, cropping intensities, and their precise location, and (b) differentiating irrigated areas from rainfed areas. **So, the critical questions that will be asked and answered by the 11 leading global researchers on the topic @ the Powell Center will be to carefully consider how we can <u>identify, conceptualize, develop and recommend</u>** <u>(by reviewing ongoing work, brainstorming new pathways, creating a knowledge warehouse through series of publications in top journals</u>**) methods and techniques for consistent and unbiased estimates of agricultural croplands over space and time by (a)** accounting for watering sources (e.g., irrigated, rainfed, other land use/ land cover (LULC)) of croplands, **(b)** elaborating on cropping intensities over a year, particularly in parts of the world where two or three crops may be grown in one year, but where cropping intensities are not known or recorded in secondary statistics; **(c)** defining the actual area and spatial distribution of croplands in the world; **(d) determining** change in croplands extent or intensity (e.g., expansion of croplands into natural vegetation, reduction due to urbanization and biofuels, change in intensity of cropping); and **(e) assessing** accuracies, errors, and uncertainties.

Proposed Start and End Dates:	April 1, 2011 – March 31, 2013
Proposed Data Release Date:	July 31, 2012
Is this a resubmission?	No
Conflicts of Interest with Reviewers:	None

2.0 Problem Statement

Food security is a pre-condition for ensuring human advancement and human dignity - <u>Mahatma Gandhi</u>
I believe that water is the only drink for a wise man- <u>Henry David Thoreau</u>
When the well is dry, they know the worth of water- <u>Benjamin Franklin</u>.

Climate models predict that the hottest seasons on record will become the norm by the end of the century-an outcome that bodes ill for feeding the world (<u>Biello</u>, 2009). Already the effects of changing climate are measurable and just in the last year alone, massive floods have occurred in many parts of the world (e.g., Pakistan), severe droughts in others (e.g., parts of Africa), and great fires in some others (e.g., Russia). In an increasingly food insecure world, there is a critical need to have a comprehensive understanding of global croplands and their water use. The reality that the "green revolution" has ended is beginning to be felt around the world. Whereas, global population continues to increase at a rate of about 100 million per year and is expected to reach 10 billion by 2050, global cropland areas are not increasing and have stagnated at approximately 1.5 billion hectares. Indeed, cropland areas have even begun to decrease in some countries with important food contribution (e.g., USA) due to increasing demand of fertile arable lands for alternative uses such as bio-fuels, encroachment from urbanization, and industrialization. Furthermore, ecological and environmental imperatives such as biodiversity conservation and atmospheric carbon sequestration have put a cap on the possible expansion of cropland areas to other lands such as forests and rangelands. These issues leave us with a fundamental and urgent question to answer: **"*how does the world ensure food security for its ballooning population <u>without having to increase</u> cropland areas and\or water allocations*?" *Indeed, an even better question to ask is*: "*how does the world ensure food security for its ballooning population <u>by reducing</u> the existing cropland areas and\or water allocations*?"** Solutions may come from bio-technology and precision farming, however developments in these fields are not currently moving at rates that will ensure global food security over next few decades. Further, there is a need for careful consideration of possible harmful effects of bio-technology. We should not be looking back 30–50 years from now, like we have been looking back now at many mistakes made during the green revolution. During the green revolution the focus was only on getting more yield per unit area. Little thought was put about serious damage done to our natural environments, water resources, and human health as a result of detrimental factors such as uncontrolled use of herbicides-pesticides-nutrients, drastic groundwater mining, and salinization of fertile soils due to over irrigation. Currently, there is talk of a “second green revolution” or even an “ever green revolution”, but clear ideas on what these terms actually mean are still debated and are evolving. The first green revolution (increase in productivity per unit of land) came through a series of factors: high-yielding plant varieties, fast growing plant varieties, irrigation, supplemental irrigation, crop intensification, and farm management (e.g., application of nutrients, herbicides, pesticides, and drainage) (see Figure 1).

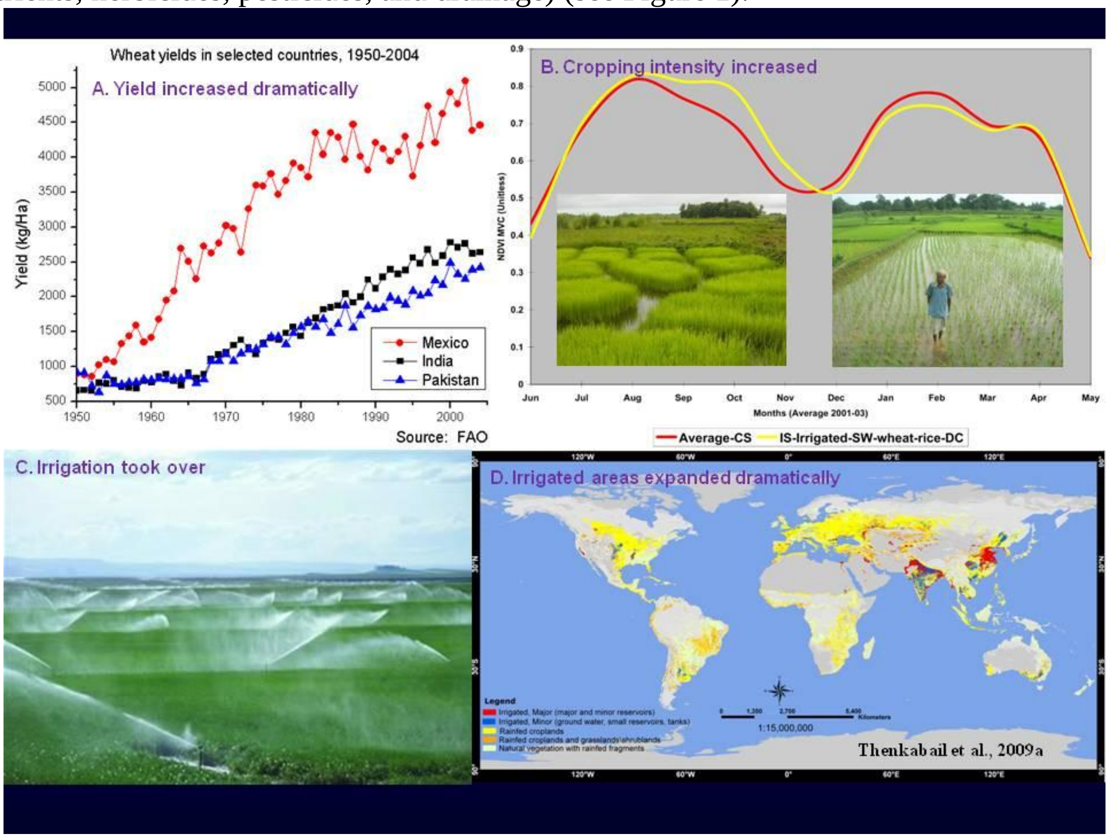

Figure 1. Green revolution (productivity per unit of land). Some of the major factors that helped achieve green revolution (years: 1955-2005) are illustrated. These factors included: (A) swift rise in yield per unit of land (e.g., through better land management, introduction of high-fast yield varieties, fertilizer, nutrients, and herbicides), (B) crop intensification (e.g., double and triple crop per year), (C) massive investments in irrigation, and (D) increase in cropland areas. (Source: Thenkabail et al., 2010a).

One of the biggest issues that is not given adequate focus is the use of large quantities of water for food production. Indeed, an overwhelming proportion (60-90%) of all human water use goes for producing our food. Of all the water used by humans for growing food, about 65 percent is consumed by green water use (for growing food in roughly 1.13 billion hectares of rainfed croplands of the world from direct rain and soil moisture from unsaturated zone) and the remaining 35 percent is consumed by blue water use (for growing food in roughly 400 million hectares of irrigated croplands of the world obtained from reservoirs, barrages, lakes, rivers, and deep aquifer groundwater) (Falkenmark, M., & Rockström, 2006, Thenkabail et al., 2009a, Siebert, S., & Döll, P., 2008, Siebert, S., & Döll, P., 2009). But such intensive water use for food production is no longer tenable due to increasing pressure for water use alternatives such as increasing urbanization, industrialization, environmental flows, bio-fuels, and recreation. ***This has brought into sharp focus the need to grow more food per drop of water leading to a "blue revolution" (see Figure 2).*** **<u>Therefore, our team will focus on brainstorming, based on existing knowledge as well as new pathways, in order to make specific recommendations on the mechanisms and strategies for producing more food in coming decades and in the twenty-first century from</u>**: (a) existing cropland areas, and (b) existing water allocations. Indeed, even better will be to focus on ideas that will focus on producing more and more food from less and less croplands and less and less water allocations- ***thus helping us to truly move towards an "ever green revolution" that combines the "best of green revolution" (a second green revolution) and a "blue revolution" (Figures 1 and 2).***

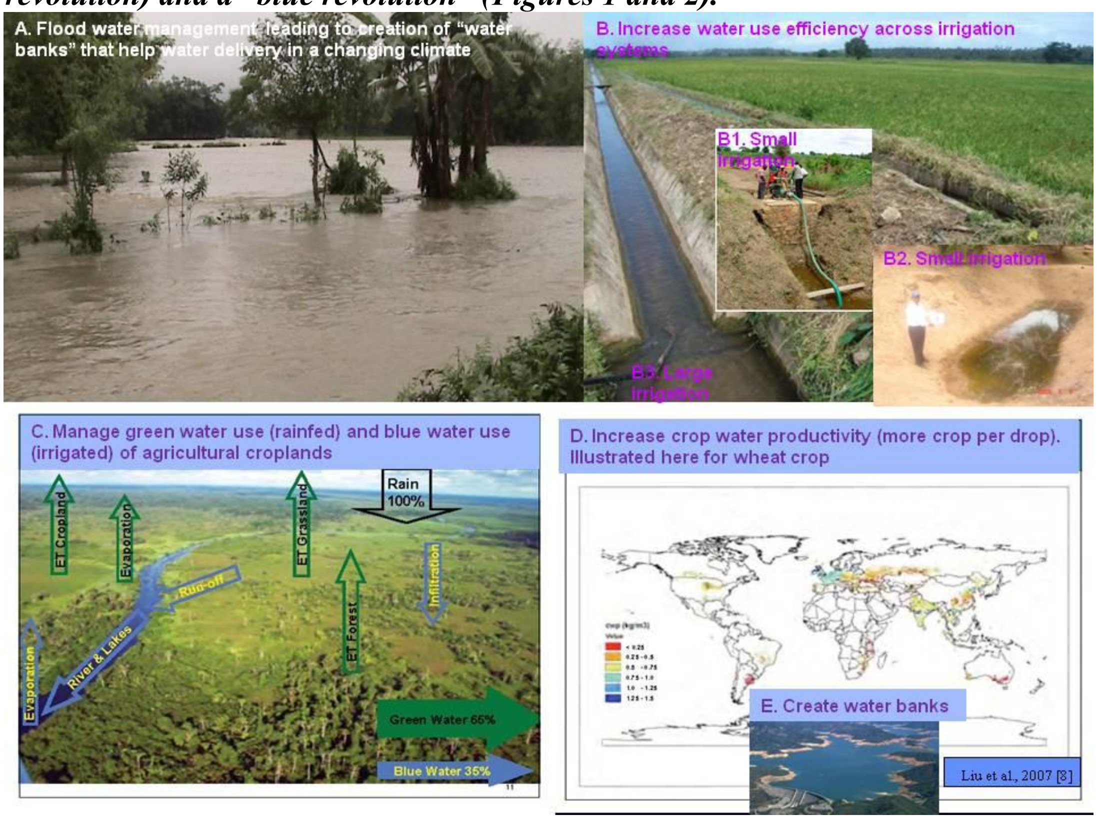

Figure 2. Blue revolution (productivity per unit of water). A blue revolution must at least include: (A) creating "water banks" (e.g., store massive floods in certain years such as the great Indus river floods of the year 2010 as "water banks" in thousands of lakes for use during lean years and develop effective water distribution system for distribute this water during drought years), (B) increasing water use efficiency (e.g., of major and minor irrigation systems), (C) advancing water management (e.g., "green water use"-water in soil moisture and by direct rain and "blue water use"- water in lakes, rivers, reservoirs, and deep aquifers management), and (D) increasing crop water productivity (e.g., crop per drop). (Source: Thenkabail et al., 2010a).

***Our* overarching goal *will be to create a “knowledge warehouse” in order to facilitate global food security in the twenty-first century by identifying and recommending scientifically sound data, methods, approaches, and products that can be used by a wide section of users concerned with the subject*.** For this we will create a framework of best practices that will lead to development of an advanced geospatial information system on croplands and their water use. Such a system will be conceptualized to be global, consistent across nations and regions by providing information such as: (a) crop types, (b) precise location of crops, (c) cropping intensities (e.g., single crop, double crop), (d) cropping calendar, (e) crop health\vigor, (f) watering methods (e.g., irrigated, supplemental irrigated, rainfed), (g) flood and drought information, (h) water use assessments, and (g) yield or productivity (expressed per unit of land and\or unit of water). Opportunities to set-up such a global system are best achieved using fusion of advanced remote sensing (e.g., Landsat, Resourcesat, MODIS) in combination with national statistics, ancillary data (e.g., elevation, precipitation), and field-plot data. Such a system, at global level, will be complex in data handling and processing and requires coordination between multiple agencies leading to development of a seamless, scalable, and repeatable methodology.

3.0 Proposed Activities

The team’s efforts will lead to establishing a lucid pathways of recommended concepts, algorithms, data plans, synergetic databases, methods, approaches, models, strategies, maps, and accuracy assessments to be published extensively (e.g., special issue of American Society’s PE&RS Journal that this PI will guest edit and publish in June, 2012- as already invited by the Journal’s editorial board and its chief editor) that will enable producing globally acceptable products using advanced remote sensing tools and methods to address one of the biggest challenges humanity will face in coming decades: *how to adequately feed a projected population of about 10 billion people by 2050 in a changing climate and increasingly water-scarce world without having to increase present allocations of croplands and\or water?.*

3.1 Satellite sensor data: In order to achieve this goal, we propose to: (a) map global irrigated and rainfed cropland areas by fusing Landsat GLS2005 data with MODIS time-series (2004-2006), secondary data (e.g., long term precipitation-temperature-evapotranspiration, GDEM), and a large collection of in-situ data; (b) map global croplands (irrigated and rainfed) by fusing Landsat GLS1990 with AVHRR time-series (1989-1991), secondary data, and national statistics; and (c) establish change in croplands, in terms of area and spatial location, in fused GLS 2005 relative to fused GLS1990.

3.2 Field-plot Data: Field-plot data (e.g., Figure 3) will be used for 3 purposes: (i) Class identification and labeling; (ii) Determining irrigated area fractions; and (iii) Establishing accuracies, errors, and uncertainties. We already have about 8000 points (Figure 3). In China, for example, we have collaborated with the Chinese Academy of Agricultural Sciences (CAAS) and the Chinese Academy of Sciences (CAS) to gather an “ideal spectral data bank of croplands” involving 1200+ points. This effort was technically supported by the PI (Dr. Thenkabail) through workshops in China and was led by CAAS and CAS for 2004-2007. In India we already have access to over 1500+ points of field-plot data collected in cropland areas during the 2003-2007 period through efforts lead by the PI (e.g., Dheeravath et al., 2009). In the United States, over 340 data points for the Ogallala aquifer areas are available for this project (Kurtz et al., 2009) during 2005-2006. In addition, we will collect data from at least another 5000 points through collaboration with world experts on croplands from different continents during the first 1.5 years of the project.

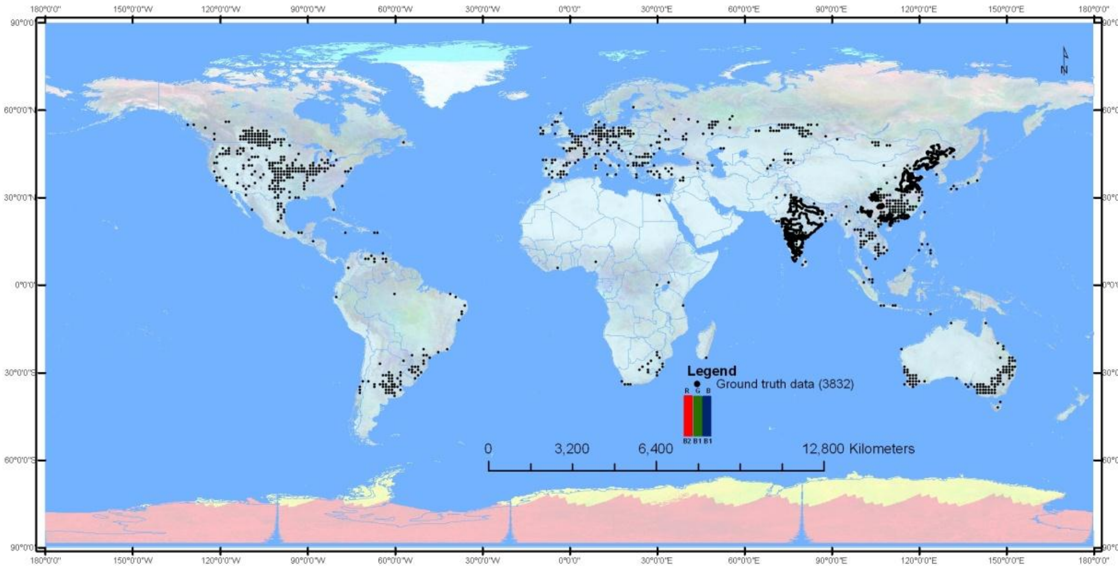

Figure 3. Global in-situ cropland data of about 8000+ points and accumulating. These data were gathered for nominal year 2005 from various missions and compiled into a single database that will be used in this project along with additional data we will gather from partnerships (e.g., USDA NASS, Chinese Academy of Sciences, Indian council for Agricultural Research), and our own field missions. For each data point we have crop type, cropping intensity, watering method (e.g., irrigated or rained), and digital photos.

3.3 Algorithm development and implementation

The proposal, team based on its extensive experience, will propose, conceptualize, develop and implement, and recommend algorithms (e.g., Ozdogan and Gutman, 2008; ongoing work of PI at USGS; various ongoing work's of co-I's). **For example, PI is currently developing** "*a knowledge-based algorithm for automated agricultural cropland mapping using fusion of Landsat, MODIS, secondary, and in-situ data*" for some of the Asian Countries. The first part of the method involves knowledge-capture (e.g., Figure 3) to understand and map agricultural cropland dynamics by: (a) identifying croplands versus non-croplands and crop type\dominance based on spectral matching techniques, decision trees tassel cap bi-spectral plots, and very high resolution imagery; (b) determining watering method (e.g., irrigated or rainfed) based on temporal characteristics (e.g., NDVI), crop water requirement (water use by crops), secondary data (elevation, precipitation, temperature), and irrigation structure (e.g., canals and wells); (c) establishing croplands that are large scale (i.e., contiguous) versus small scale (i.e., fragmented); (d) characterizing cropping intensities (single, double, triple, and continuous cropping); (e) interpreting MODIS NDVI Temporal bi-spectral Plots to Identify and Label Classes; and (f) using in-situ data from very high resolution imagery, field-plot data, and national statistics. The second part of the method established accuracy of the knowledge-captured agricultural map and statistics by comparison with national statistics, field-plot data, and very high resolution imagery. The third part of the method makes use of the captured-knowledge to code and map cropland dynamics through an automated algorithm. The fourth part of the method compares the agricultural cropland map derived using automated algorithm (classified data) with that derived based on knowledge capture (reference map). The fifth part of the method applies the tested algorithm on an independent data set of the same area to automatically classify and identify agricultural cropland classes. The sixth part of the method assesses accuracy and validates the classes derived from independent dataset using automated algorithm.

3.3.1 Spectral Matching Techniques (SMTs): Spectral Matching Techniques (SMT's) (Thenkabail et al., 2007a) are innovative methods of identifying and labeling classes. For each Landsat 30-m derived class, we will look through its characteristics over time using MODIS time-series data (e.g., Figure 4 and 5). The time-series of NDVI or other metrics are analogous to spectra, where time is substituted for wavelength. Considerable research effort has been made into hyperspectral imagery analysis and this yields a number of promising avenues, developed here, for the analysis of time series. The principle in spectral matching is to match the shape, or the magnitude or (preferably) both to an ideal or target spectrum (pure class or "end-member"). We will use the following quantitative spectral matching techniques (Thenkabail et al., 2007): (a) Spectral Correlation Similarity (SCS) - a shape measure; (b) Spectral Similarity Value (SSV) - a shape and magnitude measure; (c) Euclidian Distance Similarity (EDS) - a distance measure; and (d) Modified Spectral Angle Similarity (MSAS) - a hyper angle measure.

3.3.2 Decision tree algorithms: Decision tree (DT) rules will help group classes based on their MODIS time-series spectral profiles. Over time, NDVI for example, will vary in magnitude and structure (e.g., when it will peak and when it will be minimum) for any given pixel. Based on these variations, different classes are grouped into unique categories facilitating identification and labeling of these classes.

4.0 Participants

A total of 11 internationally renewed experts have been assembled. They include cropland experts, algorithm developers, water use experts, surface energy balance modeling experts, and agriculture experts. They come from varied levels of professional development from a USGS Mendenhall fellow to senior experts in croplands and water. The team includes experts from various geographic locations of the world- who will all bring their own unique experiences and expertise. The team is well represented in gender and ethnicity. In addition, we will have additional contributors (e.g., PE&RS special issue on global croplands and their water use guest edited by this PI).

<u>Global croplands and water use Mapping:</u> <u>(2 trip to Powell Center, USA in 2 yrs)</u>

Dr. Prasad S. Thenkabail- U.S. Geological Survey. (pthenkabail@usgs.gov; 928-556-7221). Expertise: croplands, water use, remote sensing, global mapping, team leadership; Sample web sites: https://profile.usgs.gov/professional/mypage.php?name=pthenkabail; http://www.iwmigiam.org

Dr. Cristina Milesi- NASA Ames. (cristina.milesi-1@nasa.gov; 650-604-6431). Expertise: urban irrigation, climate change, remote sensing, modeling; Sample web sites: http://ecocast.arc.nasa.gov/

Dr. Chandra Giri, U.S. Geological Survey. (cgiri@usgs.gov; 605-594-2835). Expertise: land use\land cover change, wetlands, remote sensing, and global mapping; Sample web sites: http://landcover.usgs.gov/glcc/research.php

Dr. Mutulu Ozdogan, University of Wisconsin. (ozdogan@wisc.edu; 608-890-0336). Expertise: irrigated area mapping and algorithms, global mapping, remote sensing; Sample web sites: http://www.sage.wisc.edu/index.html

<u>Global water and ET modeling :</u> <u>(2 trip to Powell Center, USA in 2 yrs)</u>

Dr. Pamela Nagler, U.S. Geological Survey. (pnagler@usgs.gov; 520-626-1472). Expertise: water use, actual evapotraspitation modeling, surface energy balance modeling, and remote sensing. Sample web sites: http://sbsc.wr.usgs.gov/about/contact/bio/nagler_pamela.aspx?id=471

Powell Center Data and Information Policy Liaison, also ET (actual water use) modeler : (2 trip to Powell Center, USA in 2 yrs)

Dr. Isabella Mariotto, post-doc, U.S. Geological Survey. (imariott@nmsu.edu; 575-635-5838). Expertise: water use, actual evapotraspitation modeling, surface energy balance modeling, and remote sensing. Sample web sites: http://biology-web.nmsu.edu/bgso/web/grads.html

Technical Liaison (to work with Powell computing Staff), also ET (actual water use) modeler : (2 trip to Powell Center, USA in 2 yrs)

Dr. Michell Marshall, Mendenhall post doc, post-doc, U.S. Geological Survey. (mmarshall@umail.ucsb.edu; 805-893-8322). Expertise: water use, actual evapotraspitation modeling, surface energy balance modeling, and remote sensing. Sample web sites: http://chg.geog.ucsb.edu/about/mission.php

Accuracies and Errors: (2 trip to Powell Center, USA in 2 yrs)

Prof. Russell G. Congalton, University of New Hamphshire, (russ.congalton@unh.edu; 603-862-4644). Expertise: errors, accuracies, and uncertainties, remote sensing; Sample web sites:
http://www.unh.edu/geography/index.cfm?id=96420137-A5DB-A4E4-A8BB82BEC6E15705
http://www.directionsmag.com/pressreleases/dr-russell-g-congalton-named-editor-in-chief-of-photogrammetric-engineering/113702

Non-croplands (forests, ecosystems): (2 trip to Powell Center, USA in 2 yrs)

Prof. Alex Finkral, Northern Arizona University, (alex.finkral@nau.edu; 928-523-1378). Expertise: forestry, ecosystems, and carbon modeling. Sample web sites:
http://www.fordev.nau.edu/cms/content/view/561/771/

International experts on Croplands and water use: (1 trip to Powell Center, USA in 2 yrs)

Prof. Jerry Knox, Centre for Water Science, Cranfield University , U.K.,-Europe and Africa (j.knox@cranfield.ac.uk; +44 (0)1234 758365). Expertise: crop modelling, agricultural water management in Europe and Africa, GIS modeling and remote sensing.
http://www.cranfield.ac.uk/sas/aboutus/staff/knoxj.html

Prof. Songcai You- Chinese Academy of Agricultural Sciences, China. (yousc@ieda.org.cn; 86-10-82109571 ext.3227). Expertise: croplands of China, Asian expertise, and remote sensing. Sample web sites: http://english.irsa.cas.cn/

Dr. Obi Reddy Gangalakunta- Indian Council for Agricultural Research, India. (obireddy@nbsslup.ernet.in; +0712-2500545, extn.: 115, 111). Expertise: croplands, water use, statistics, and remote sensing. Sample web sites: http://nbsslup.nic.in/

Dr. Bernard Rudorff- National Institute for Space Research, INPE, Brazil. (bernardo@dsr.inpe.br; 55-12-3208-6490). Expertise: remote sensing, croplands, water use, statistics, and remote sensing. Sample web sites: http://www.inpe.br/ingles/index.php

Data contributors and supporters: (0 trip to Powell Center, USA in 2 yrs)

Dr. Andrew Nelson, Head of Remote Sensing and GIS, International Rice Research Institute (IRRI), P.O. Box 933, Manila 1099, Philippines, Phone: +63 (2) 845 0563; Email: a.nelson@cgiar.org; Sample web sites: http://irri.org/

Dr. Jinlong Fan (GEO Secretariat, Geneva): Agriculture, remote sensing. E-mail: jfan@geosec.org ; Sample web sites: http://www.earthobservations.org/geoss_ag.shtml

5.0 Timetable of Activities

The team effort leads to number of "**think tank**" creating advanced "knowledge warehouse" on global croplands and their water use. **First**, we will make a significant contribution towards agricultural cropland mapping and water use modeling that will include advance remote sensing driven methods for crop detection, crop type identification, development of cropland spectral data bank, separation of irrigated croplands from rainfed croplands, and water use assessments of irrigated crops and rainfed crops. **Second**, the "think tank" activity will bring clarity and provide a clear road-map to help accurately determine (e.g., through publications): (a) green water use (by rainfed croplands) and (b) blue water use (by irrigated croplands), (c) food production, (d) dynamics of virtual water trade, and (e) scenario modeling. The blue water use by irrigated crops and green water use by rainfed crops can be accurately assessed, based on information such as: (a) crop type, (b) precise spatial location of crops (e.g., latitude), (c) cropping intensity, (d) crop calendar, (e) watering methods (e.g., irrigation, rainfed), (f) watering source (ground water, surface water), (g) irrigation type (e.g., sprinkler, gravity). How best to achieve these goals will be published by the "think tank". **Third**, it will highlight approaches and methods of handling large data volumes, fusing multiple-sensor data, identify and propose necessary algorithms to process data, identify key products that are scalable, and enumerate on uncertainties, errors, and accuracies. **Finally**, the proposal results will contribute to the major strategic International programs supported by the LCLUC program by responding to the IGBP/IHDP Global Land Project, Global Earth Observing (GEO), Global Earth Observing System of Systems (GEOSS)-specifically its Global Agricultural Monitoring System (AG-07-03). **Time-table of activities:**

April-May, 2011: communication of "think tank" members and their collaborators. Finalize a strategy on how, where, and when to publish our ideas;

June, 2011: First meeting of the "think tank" team at the Powell center for 3 days. The objective of the meeting will be to: (a) discuss innovative ideas on cropland mapping and their water use modeling that is global, scalable, and repeatable, (b) share-challenge-contribute new and innovative ideas that will help propagate practical solutions to food security in the twenty-first century; and (b) assign key role on approaches and methods to each member that will lead to a peer-reviewed publication in a special issue of a high quality journal and\or published as a book (Publisher: Taylor and Francis).

July, 2011-May, 2012: analyze data, bring out key ideas, develop outlines of lead papers, and write key papers that help promote global food security through cropland and their water use.

June 2012: Second meeting of the team. This meeting will: (a) discuss key ideas and related papers written by "think tank" members; (b) review materials that will be sent to publishers; and (c) highlight key achievements of the "think tank" and its true contribution to global food security in the twenty-first century.

March 2013: Ensure submission of critically peer-reviewed articles for publication in a journal (or to a publishing house for a book).

6.0 Anticipated Results and Benefits

Expected outcomes will include:

(A) <u>**Framework document**</u> on state-of-art Knowledge-base on global croplands and their water use that is cutting-edge and pioneering;

(B) **<u>Publication of a special issue of a journal</u>** (e.g., the editorial board and the editor in chief of the **<u>American Society of Photogrammetric Engineering and Remote Sensing (PE&RS) has invited PI of this proposal to guest edit a special issue tentatively entitled</u>**: *"Remote Sensing of Global Croplands and their Water Use for Food Security in the Twenty-First Century".* **Through this effort, we seeks broader consensus as well as new ideas which will add to the "**Framework document on state-of-art Knowledge-base on global croplands and their water use that is cutting-edge and pioneering" conceptualized, tested, and published by the PI's and co-I's of this proposal;

(C) **<u>Implementation of the ideas (A and B above) at the national and sub-national level</u>** (e.g., several developing countries such as Brazil, India, China, South-East Asian Nations as a start. For example, the PI is currently guiding a post doc based in International Rice Research Institute in Philippines on mapping rice areas of South Asia using MODIS time series, Landsat, secondary, and a large volume of in-situ data. A rice map for 2000-2001 and 2009-2010 are already available and currently reviewed for publication in peer-reviewed journal- http://beta.irri.org/news/images/stories/ricetoday/9-3/Map.pdf);

(D) **<u>Web portal:</u>** our idea is to publish and disseminate all ideas, concepts, links, datasets, models, algorithms, and maps produced through this proposal in a web\data portal (e.g., one past example of PI lead effort: http://www.iwmigiam.org).

Literature Cited

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